Modeling Sediment Erosion and Redistribution in Fine-Grained Shelf Environments

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LONG-TERM GOAL

My long-term goal within the EuroSTRATAFORM program is to increase our ability to predict sediment transport in fine-grained regions of the continental shelf. Field work and the development and application of models during STRATAFORM increased our understanding of these processes and improved our ability to predict them. EuroSTRATAFORM offers several fine-grained shelf sites with characteristics (forcing, margin configuration) that contrast with the Eel shelf STRATAFORM study area. Testing our conceptual and numerical sediment transport models at these sites is an important goal of the EuroSTRATAFORM shelf process studies.

OBJECTIVES

The objectives of this project are to 1) measure alongshelf and across-shelf variations in critical shear stress and erosion rates; 2) compare sediment transport rates calculated with measured erosion rates to measured transport rates; and 3) explore the implications of spatial variations in critical shear stress on patterns of sediment transport and deposition. The objective during FY02 (initial, partial year of funding), was to have an erosion chamber built, make a preliminary set of measurements of erosion rates on the Apennine coast of the Adriatic, and plan for a comprehensive set of measurements during the main Apennine field study.

APPROACH

My approach is to use an erosion chamber that fits onto a core (or subcore) tube to make shipboard measurements of critical shear stress and rates of erosion of seabed sediment and to use the results to parameterize erosion rates of fine-grained sediment in sediment transport models.

WORK COMPLETED

I used an erosion chamber borrowed from Larry Sanford (Horn Point Lab, Univ. of Maryland) to make a preliminary set of erosion measurements during a cruise in April, 2002, on the Apennine coast of the Adriatic. Results of these measurements are discussed below. An erosion chamber is being built for me at Horn Point Lab and will be completed in early October, 2002. During several meetings this year (Seattle in June, Winchester UK in September), plans have been developed for a sediment transport field program along the northwest Adriatic coast from the Po River mouth to the Gargano Peninsula to be carried out from November 2002 – May 2003. My plans are to measure spatial variations in critical

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14. ABSTRACT

My long-term goal within the EuroSTRATAFORM program is to increase our ability to predict sediment transport in fine-grained regions of the continental shelf. Field work and the development and application of models during STRATAFORM increased our understanding of these processes and improved our ability to predict them. EuroSTRATAFORM offers several fine-grained shelf sites with characteristics (forcing, margin configuration) that contrast with the Eel shelf STRATAFORM study area. Testing our conceptual and numerical sediment transport models at these sites is an important goal of the EuroSTRATAFORM shelf process studies.

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shear stress and erosion rates along the shelf in conjunction with measurements of sediment grain size, carbonate and organic content, porosity, bioturbation, and physical structures planned by Rob Wheatcroft and Chuck Nittrouer.

RESULTS

Critical shear stress and erosion rates were measured on core samples collected along two cross-shelf transects, one offshore of the Pescara River and the other offshore of the Tronto River in the northwestern Adriatic during a cruise in April 2002. Measurements were made using a Gust erosion chamber fitted onto the top of 10-cm-diameter subcores extracted from box cores collected at depths ranging from 19 m-57 m. The erosion chamber applied a range of known shear stresses (from 0.01 – 0.4 Pa) to the sediment surface of the core. Each value of shear stress was maintained for 20-30 min (Figure 1). Water in the chamber was replaced by pumping seawater into the chamber; water leaving the chamber passed through a turbidity sensor that recorded turbidity levels every 0.5 s. The water was then collected in bottles, filtered, dried and weighed to obtain suspended particle mass. The results were used to calibrate the turbidity measurements. Filtered material was then combusted to obtain organic fraction.

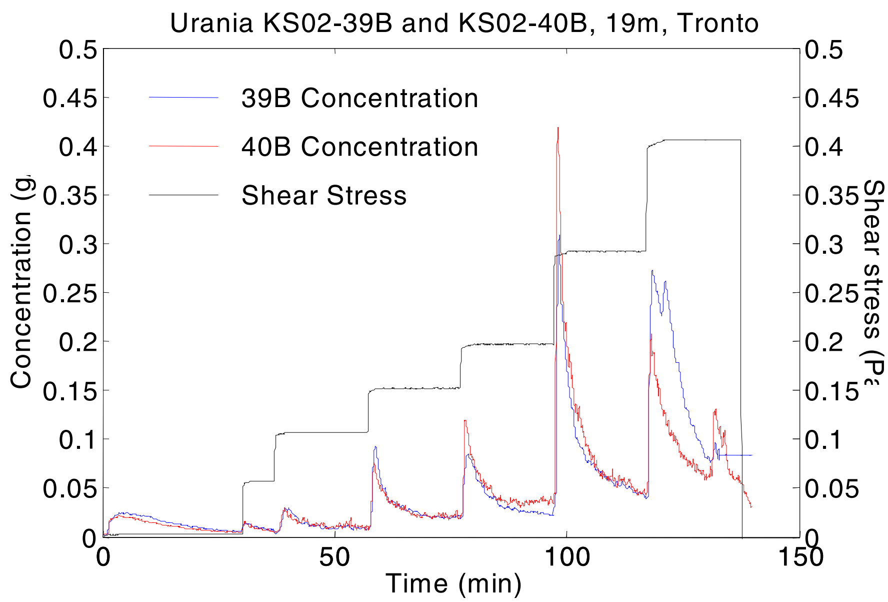

Figure 1. Bed shear stress (black line) and suspended sediment concentration (blue and red curves) during an erosion test of a pair of samples collected at a depth of 19m offshore of the Tronto River. Each value of stress was maintained for 20 min. Initially concentration spiked, then decreased approximately exponentially as the turbid water was replaced by water with background levels of concentration. The large spike at a shear stress of 0.3Pa is interpreted to represent the critical shear stress for significant resuspension of sediment at this site.

Measurements were made on a total of 9 subcores having relatively smooth, undisturbed surfaces. Of these, 4 were collected while there was water still on the core surface; for the rest, seawater was added after recovery. Water overlying the sediment surface was often quite turbid. At the lowest shear level (0.01 Pa) this water was pumped out of the erosion chamber and the water cleared. At shear stresses of 0.1-0.3 Pa, particles began to be eroded from the sediment surface (Figure 1). Laboratory analysis showed that ~25% of the suspended material was organic at the lowest shear stresses; organic fraction decreased with increasing shear stress to values of about 5% (Figure 2). Based on filtering times, the eroded particles appeared to be very fine. Samples of the bed surface were collected for size analysis by Tim Milligan. Results of this analysis reveal little to no change in grain size of the sediment surface before and after the erosion experiments. This suggests that erosion rates were limited by cohesion rather than grain size. The modal size of the sediment was in the medium to coarse silt range (~30 µm). Suspended sediment concentrations increased abruptly with each increase in shear stress, followed by a roughly exponential drop toward the ambient background concentration as all of the sediment able to be mobilized at each step in shear stress was suspended and removed (Figure 1).

A distinct, maximum concentration peak, interpreted as being the critical shear stress for significant resuspension, was observed in all samples. For all but the deepest sample (57 m), this occurred at a shear stress of 0.3 Pa (Figure 1); a critical shear stress of 0.4 Pa was recorded for the deepest sample (also the sample furthest to the south). These values are higher than critical shear stresses determined from suspended sediment measurements on some other fine-grained shelves such as the Eel shelf, northern California, where the critical shear stress for muddy sediment is about 0.1 Pa. Higher values may be related to the relatively high carbonate content of the sediment in the region of the Adriatic shelf where the measurements were made (up to 30%). Combined with the relatively low energy wave environment of the northern Adriatic, it appears that sediment in water depths greater than 20-25 m is infrequently resuspended by waves (Figure 3). Relatively strong currents combined with waves would have a greater potential for transport. This potential will be addressed during the field study planned for 2002-2003. The field study will also provide near-bed measurements of waves, currents and suspended sediment concentration. With these, we can determine whether the critical shear stresses for resuspension suggested by the erosion chamber data are consistent with the stresses required to significantly increase near-bed turbidity in the field.

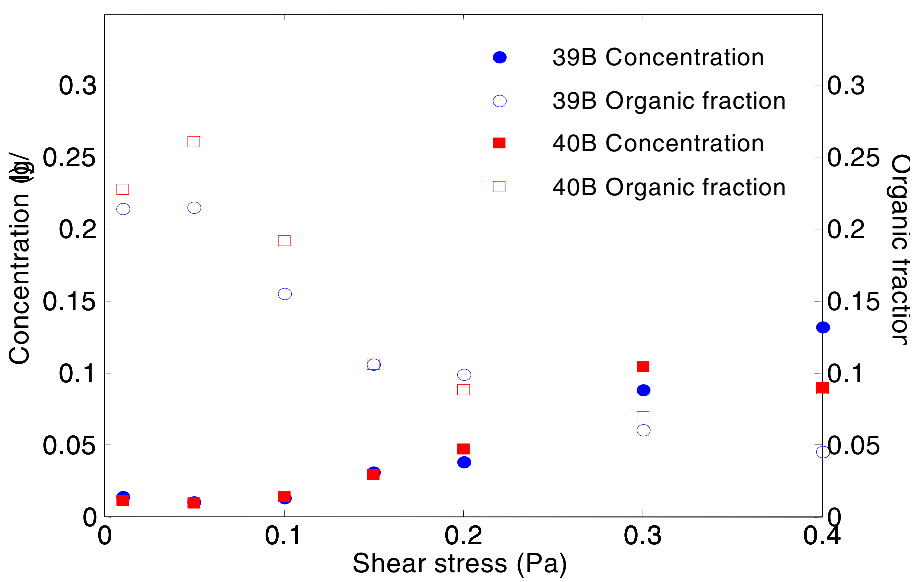

Figure 2. Average concentration (filled symbols) and organic content (open synbols) as a function of sheear stress for the 19m site off the Tronto River. At low shear stresses (≤ 0.1Pa), 15-25% by weight of the suspended material was organic. As shear stress increased, average concentration increased and organic fraction decreased to < 10% at shear stresses ≥ 0.3Pa.

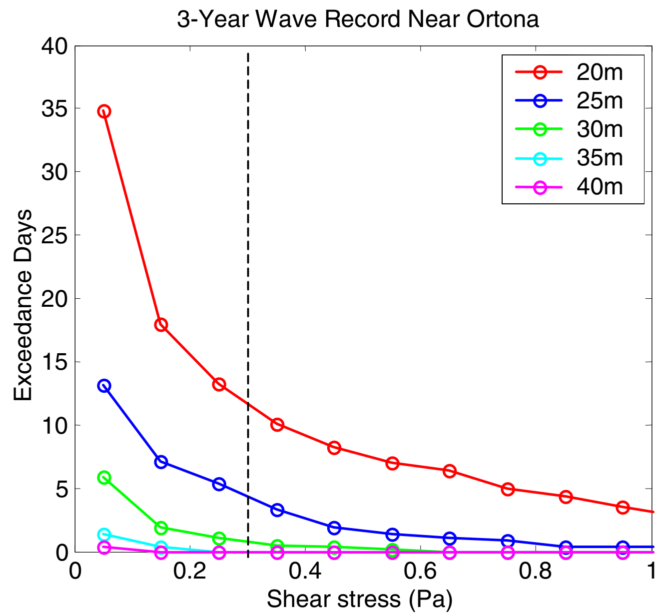

Figure 3. Number of days of wave-generated bottom stresses exceeding indicated values during the 3-year period 1999-2001 based on wave data from the Adriatic near Ortona. The vertical dashed line corresponds to the critical shear stress indicated in the erosion chamber results. At depths greater than 20-25 m, wave-generaged bottom stresses rarely exceed 0.3 Pa, suggesting low sediment transport potential.

The erosion chamber also provides information about erosion rates. Essentially all of the sediment with a critical shear stress less than or equal to a given imposed stress is eroded during the ~20 min for which the stress is held constant. The eroded mass for each value of shear stress can be obtained from the filtered samples. Relating the mass eroded to the shear stress yields a power-law relationship (straight line on a log-log plot; Figure 4). Similar results were found by Sanford and Maa (2001) using data from the Sea Carousel, an in-situ flume for measuring critical shear stress and erosion rates. The power-law relationship between eroded mass and shear stress can be transformed into a graph of critical shear stress as a function of depth if the bulk density of the surficial sediment is known and the stress is assumed to be the critical shear stress for the sediment eroded during each shear-stress step. Critical shear stress as a function of depth or mass eroded can be formulated into an entrainment function that can then be used in sediment transport calculations (e.g., Sanford and Maa, 2001).

IMPACT/APPLICATION

Critical shear stress and erosion rates are among the most poorly constrained parameters in shelf sediment transport calculations. These measurements will improve our ability to specify these important parameters.

TRANSITIONS

Erosion rate formulations developed in this study will be available to other investigators modeling sediment transport in EuroSTRATAFORM (e.g., Courtney Harris, Alan Niederoda) as soon as they have been determined.

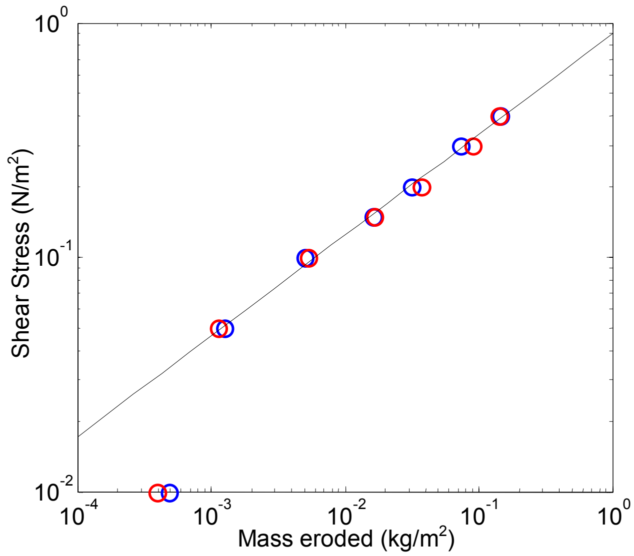

Figure 4. Mass eroded at the end of each step in shear stress increases as a function of shear stress. The data fall along a line on this log-log plot (except at the lowest shear stress during which the initial turbidity in the chamber was cleared), indicating a power-law relationship between eroded mass and shear stress.

RELATED PROJECTS

The models I plan to use in this project were developed in the STRATAFORM program.

REFERENCES

Sanford L.P. and J.P.Y. Maa, 2001. A unified erosion formulation for fine sediments. *Marine Geology* 179(1-2): 9-23.